Phase-Resolved Reconstruction and Forecast of Ocean Wavefields Using Scanning-Sensing Wave Measurements

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Award Number: N00014-08-1-0694
http://www.mit.edu/~vfrl/

LONG-TERM GOAL

To develop and demonstrate an advanced capability of deterministic reconstruction and (short-time) forecasting of realistic ocean wavefield evolution, using scanning wave sensing data and efficient phase-resolved nonlinear wave simulations.

OBJECTIVES

Of special interest and focus is incorporation and assimilation of radar measurements of ocean surface waves in phase-resolved simulation of nonlinear ocean wavefield evolution. To reach this objective, fundamental research and technical developments in the following four areas are required:

1. Development of a phase-resolved wave reconstruction and prediction capability incorporating with radar sensed wave data

2. Understanding of reliability/accuracy/robustness and limitations of the overall approach

3. Assessment of effects of noise, uncertainties, and interpretation errors in radar measurements upon the accuracy of wavefield prediction

4. Direct quantitative comparisons between wave model prediction and field measurements.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2009**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Phase-Resolved Reconstruction And Forecast Of Ocean Wavefields Using Scanning-Sensing Wave Measurements**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,Department of Mechanical Engineering,Center for Ocean Engineering,Cambridge,MA,02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Code 1 only

14. ABSTRACT
To develop and demonstrate an advanced capability of deterministic reconstruction and (short-time) forecasting of realistic ocean wavefield evolution, using scanning wave sensing data and efficient phase-resolved nonlinear wave simulations.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

APPROACH

We develop and apply a comprehensive deterministic computational model for intermediate scale, O(10)km, wave environment prediction by integrating whole-field and multiple-point direct measurements of the ocean wave and atmospheric environment with nonlinear simulation-based reconstruction of the wavefield. The wave reconstruction is based on phase-resolved simulation of nonlinear surface wave dynamics, and utilizes hybrid (from different types of sensors) measurements that may contain noise, uncertainty and gaps (Wu 2004; Yue 2008). The simulations will incorporate physics-based wind forcing, wave-breaking dissipation, and current models.

WORK COMPLETED

The main objective of this research is on the understanding of feasibility and reliability of applying nonlinear wavefield simulations together with radar sensed wave data to obtain a phase-resolved reconstruction and prediction of realistic ocean wavefield evolution. We thus focus on the accuracy of wave reconstruction and forecasting that might be affected by imperfect wave data or misinterpretation of the predicted wavefield.

- Investigate the effects of uncertainty and incompleteness in scanning sensed wave data (such as shadows in radar sensed data) upon the accuracy and reliability of the wave reconstruction and prediction. Of special interest is the determination of wave predictable regions for given hybrid sensed wave data.

- Apply the high-resolution wave reconstruction and forecasting capability to evaluate the accuracy, effectiveness and robustness of the interpretation schemes in transforming radar signals to ocean wave information. In particular, we developed algorithms based on nonlinear wave reconstruction to determine the wave information in shadow zones of radar measurements and to extract current speed and direction from the radar sensed surface data.

- Perform direct comparisons between quantitative field radar measurements and phase-resolved wave reconstruction/forecasting to evaluate and quantify the validity, efficacy, and limitations of the overall approach.

RESULTS

We extend the phase-resolved wave reconstruction/prediction model to include radar sensed wave data, develop algorithms based on the nonlinear reconstruction for determining the wave information in shadows of radar measurements and for extracting current information from the radar data, and apply the wave reconstruction and forecasting capability to synthetic and realistic ocean waves. We present sample results on the extraction of current information from radar wave measurements and on the understanding of the accuracy of the reconstructed/predicted wavefield based on specified radar sensed wave data as a function of space and time.

The presence of current affects the wave characteristics. In order to obtain a proper prediction of wavefield evolution, the effect of current must be included in wave modeling. Thus, accurate determination of current speed and direction from radar sensed wave data is of significance. The developed wave reconstruction scheme can be applied to properly determine the current information from radar sensed wave data. A sample application of this capability is illustrated in figure 1 which shows the time variation of the correlation coefficient between the reconstructed/predicted wavefields and the WAMOS radar sensed wave data. The radar wave data is used in the reconstruction at t/T=0 only. In the reconstruction, current is treated in three different ways: (i) without current; (ii) setting current $U=U_{radar}$ = 0.66m/s and direction $\theta = 337^o$ (which are estimated empirically from radar data); and (iii) treating current speed U and direction θ as unknowns that are to be determined by optimization in reconstruction. In the third treatment, we obtain U = 0.89 m/s and $\theta = 341^o$, which give the best prediction of the wavefield evolution by comparing to the radar data (not used in the prediction), as shown in figure 1. This example indicates that it is possible to obtain a better estimate of current information from radar sensed wave data using the wave reconstruction algorithm.

For a given radar sensed wave data in a certain domain *D* at a particular time (say *t*=0), we can reconstructed the wavefield in *D* at *t*=0 and then use the nonlinear wave simulation to predict the evolution of the reconstructed wavefiled in *D* for *t* > 0. In the evolution of the wavefield, waves outside *D* (that are not represented in the radar sensed data) would enter slowly into *D* and deteriorate the predicted wave motion near the boundary of *D*. The region in *D* affected by this increases with time. Eventually the whole domain of *D* is influenced and the reliability of the predicted wave motion is completely lost. In other words, for a given radar sensed wave data in *D* at time *t* =0, there exists a predictable region *Q* inside which the wavefield evolution can be reliably predicted based on the reconstructed wavefield in *D* at *t*=0. In general, *Q* coincides with *D* at *t*=0, and then becomes smaller and moves in the wave direction as the evolution time increases. *Q* is dependent on the properties of the wavefield, wave propagation direction, and size of *D*.

To illustrate this, we use a synthetic radar data in a domain *D* of 1km × 1km at a particular time (say *t*=0), as shown in figure 2a, to obtain a reconstruction of the wavefield at *t*=0 and then to predict the subsequent evolution of the wavefiled. The radar wave data is chosen from a larger synthetic wavefield of 30 km × km, whose evolution is computed using a direct phase-resolved wave simulation tool, SNOW. This synthetic wavefield is initially given by a JOHNSWAP spectrum with significant wave height H_s = 12 m, peak period *T*=13s, enhance parameter γ=5, and spreading angle $\Theta = 80^o$. The major propagation direction is along the positive *x* direction. To understand the reliability/accuracy of the predicted wavefield evolution with time, we compare the time history of wave elevations in the predicted wavefield with the original synthetic wavefield at three locations A, B, C, as shown in figure 2a. The comparisons are shown in figure 2b. It is seen that the predicted wave elevations at A and C start deviating largely from that of the original wavefield at t/T ~2 as A and C are respectively closer to the upstream and side boundaries of *D*. Good comparison for the elevation at B extends to t/T ~5 as B is located near the downstream boundary of *D*. This confirms the existence of a predictable region *Q* for a specified radar wave measurement in *D* at *t*=0, which becomes smaller as the wavefield evolution continues.

IMPACT/APPLICATIONS

Advances in large-scale nonlinear wave simulations and ocean wave sensing have recently made it possible to obtain phase-resolved high-resolution reconstruction and forecast of nonlinear ocean wavefields based on direct sensing of the waves. Such a capability will significantly improve ocean-surface sensing measurements and deployment, and data assimilation and interpretation, by providing a comprehensive wave-resolved computational framework. Another important potential application of this is to greatly increase the operational envelopes and survivability of naval ships by integration of such capability with ship-motion prediction and control tools.

RELATED PROJECTS

The present project is related to the project entitled "High-Resolution Measurement-Based Phase-Resolved Prediction of Ocean Wavefields" (N00014-08-1-0610). The present project focuses on the understanding of fundamental algorithms and accuracies/reliabilities of the developed deterministic wavefield reconstruction and prediction capability while the related project focuses on the application of the wave reconstruction/prediction capability to realistic ocean environment.

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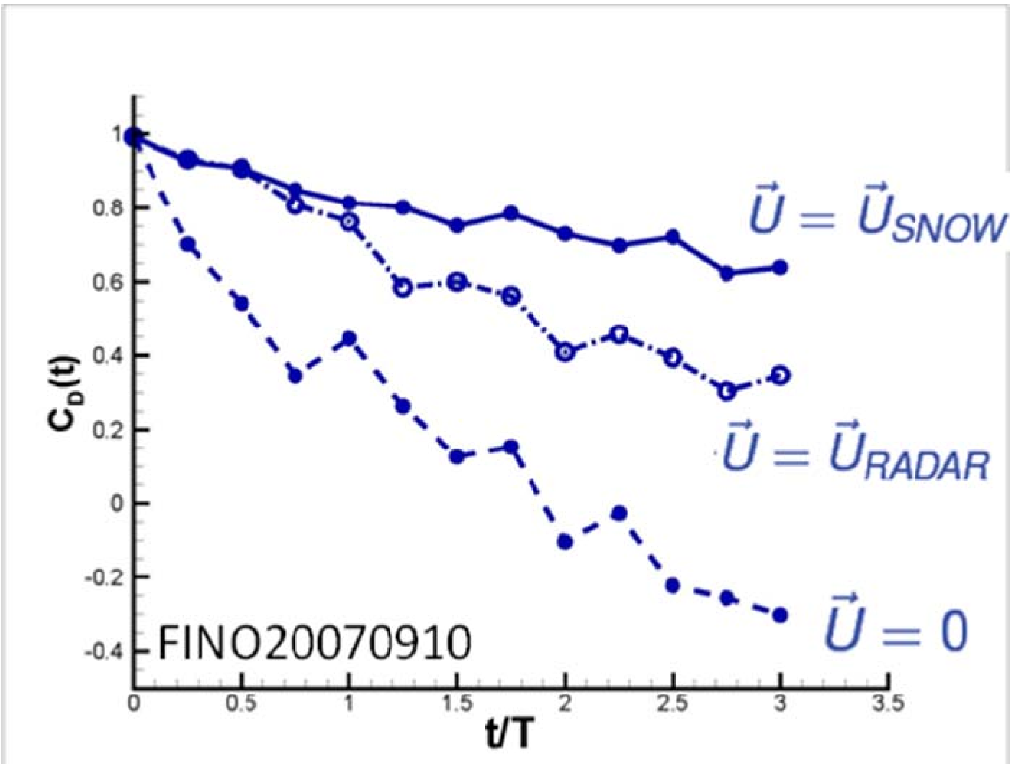
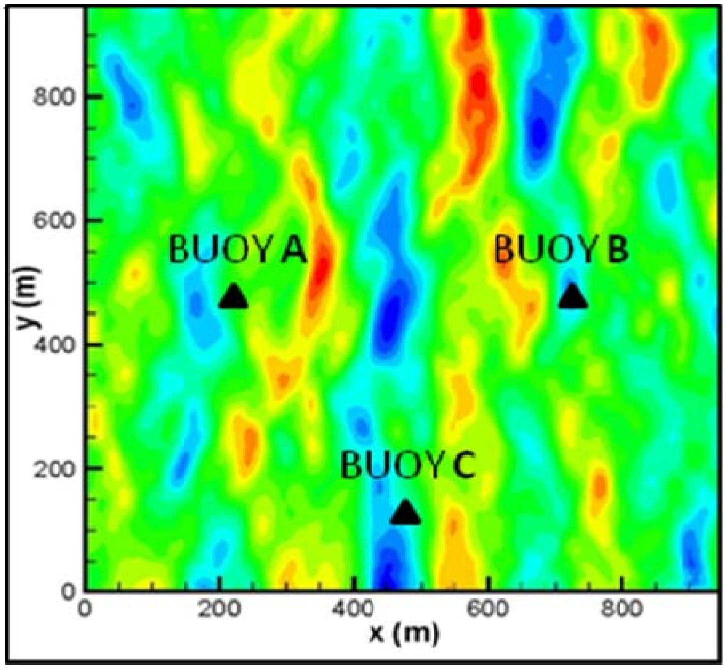
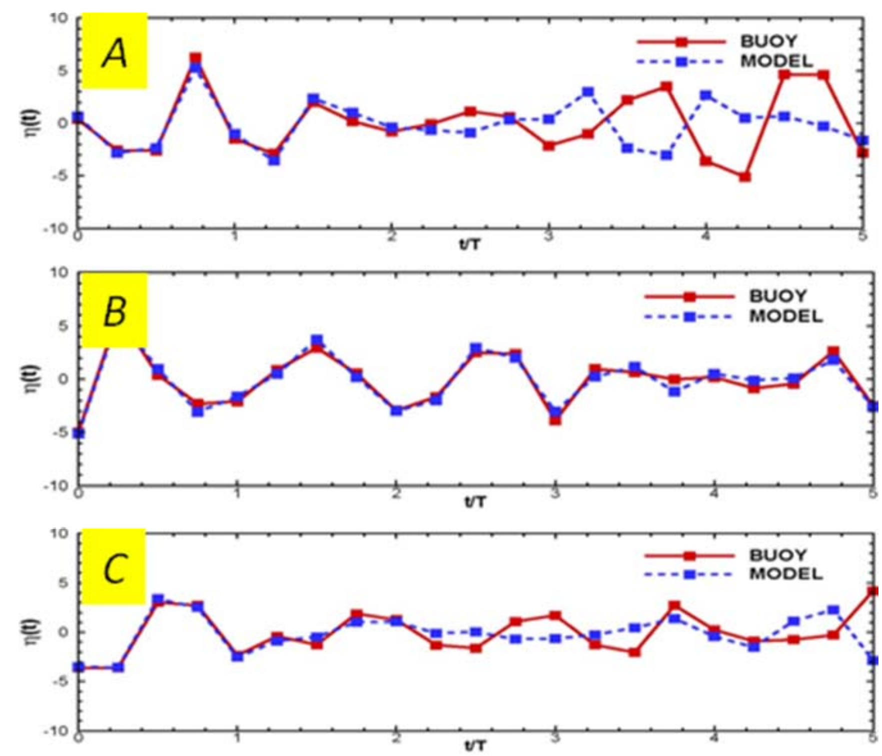


Figure 1: Correlation coefficients between the reconstructed/predicted wavefields and the original radar sensed wave data as a function of time. Wave reconstructions are obtained based on the radar sensed wave data at t/T=0 with current speed U=0, U=U_{radar} = 0.66m/s (estimated empirically from radar data), and U_{snow}= 0.89 m/s (determined by optimization in wave reconstruction).



(a)



(b)

Figure 2. (a) A surface wave image in a 1km × 1km domain, chosen from a large synthetic wavefield of 30km × 30 km, used as radar sensed wave data for wave reconstruction. (b) Comparison of time histories of wave elevations in the reconstructed/predicted and original wavefields at locations A, B, and C: results from the original wavefield (read line) and from the predicted wavefield (blue line).